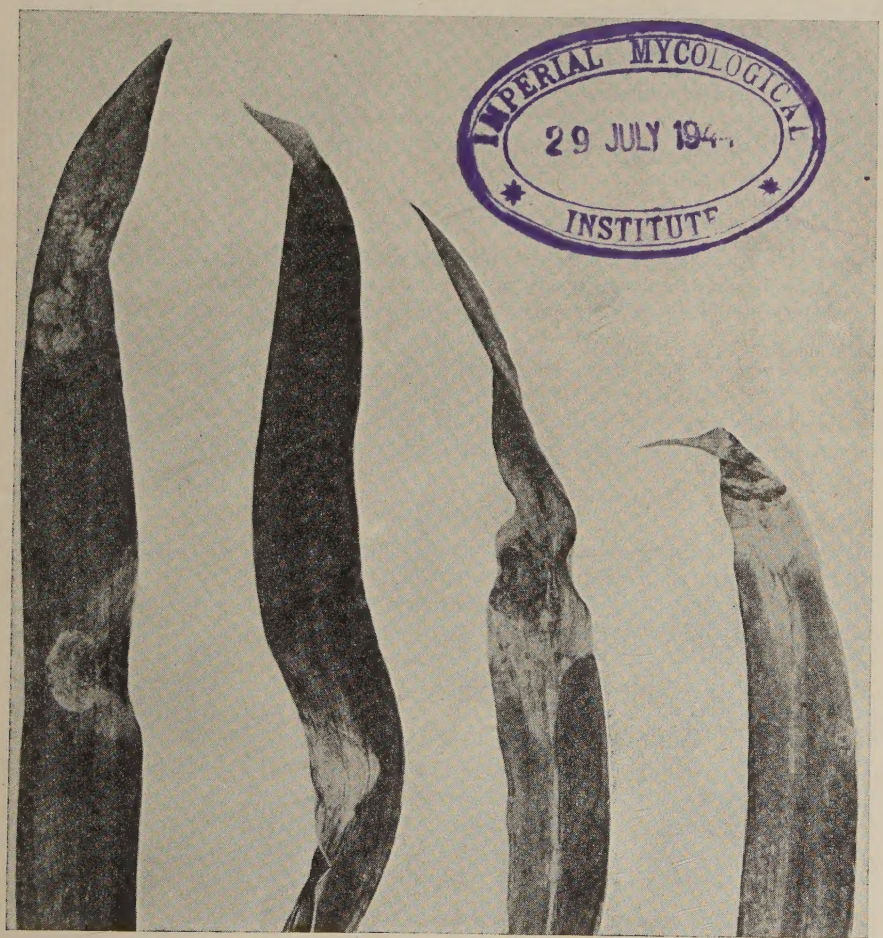
Bulletin 790

January 1943

Alternaria Blight of Carnations Caused by *Alternaria Dianthi* Stev. and Hall

J. M. Bickerton



IMPERIAL MYCOLOGICAL
29 JULY 194-
INSTITUTE

Published by the
Cornell University Agricultural Experiment Station
Ithaca, New York

Received for publication July 1, 1942

CONTENTS

	PAGE
Names of the disease	3
History and range	3
Economic importance	4
Suscepts	4
Plants affected	4
Varietal susceptibility	5
Symptomatology	6
Morphologic symptoms	6
Etiology	7
Pathogenicity	9
Life history of the pathogen	9
Sources of inoculum	9
Inoculation	12
Infection courts	12
Incubation	13
Control	17
Manipulation of cultural practices	17
Application of fungicides	19
Summary	25
References	28

ALTERNARIA BLIGHT OF CARNATIONS CAUSED BY *ALTERNARIA DIANTHI* STEV. AND HALL[1]

J. M. BICKERTON

Carnations (*Dianthus caryophyllus* Linn.) are one of the major cut-flower crops of the American florist.[2] Growers in New York have regularly suffered heavy losses of carnations from an apparent complex of diseases. Because of this situation the author conducted an investigation over a period of four years (1937–1940) in cooperation with carnation growers on Long Island. The purpose of the study was to determine the nature of these diseases and to establish means for their control. This paper presents the results of a study of Alternaria blight, which is one of the major diseases occurring on Long Island.

NAMES OF THE DISEASE

Alternaria blight of carnations has been referred to by many names in the past. Orton (25) and Clinton (5) called the disease *carnation spot.* This designation is confusing in that there are other spot diseases of carnations. Stevens and Hall (28) named the disease *Alternariose of carnations.* Growers have referred to it by such names as *black spot, blue stem, blue spot,* and *branch rot.* The latter name has also been applied to *Fusarium wilt* of carnations. The term *Alternaria blight,* first used by Guba (12), is probably the most descriptive in distinguishing this disease from all others affecting carnations.

HISTORY AND RANGE

On February 6, 1906, A. F. Woods delivered a lecture[3] on carnation diseases before the Washington Florists' Club in which he called particular attention to a new disease that was prevalent in this country during 1905 on carnations of the Mrs. Lawson type. The occurrence and seriousness of the disease in 1905 was also reported by Orton (25). Further reference to the disease was made by Woods (29) in 1907, and by Clinton (5) who found the disease in a greenhouse in Connecticut. In 1909, Stevens and Hall (28) in North Carolina published the first adequate description of Alternaria blight with proof of the pathogenicity of the causal organism.

Subsequently the disease was reported[4] from California, Delaware, Indiana, Maryland, Massachusetts, Michigan, Missouri, New Jersey, New York, Ohio, Pennsylvania, Texas, Virginia, and Wisconsin. In addition, the writer has observed it in Colorado and Illinois. Outside the United

---

[1]Also presented to the Faculty of the Graduate School of Cornell University, February 1941, as part of a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy. This study was made possible by funds supplied by the New York Florists' Club.

AUTHOR'S ACKNOWLEDGMENTS. The author wishes to express his sincere appreciation of the invaluable criticisms and encouragement of Dr. L. M. Massey, Dr. C. E. F. Guterman, Dr. F. A. Haasis, and Dr. A. W. Dimock, of Cornell University under whose direction this work was done. He is also indebted to Dr. F. M. Blodgett of Cornell University for his advice in the statistical analysis of data. Thanks are due Mr. Howard H. Campbell for furnishing laboratory and office facilities in the Nassau County Farm Bureau office; and to the various Long Island carnation growers whose cooperation made the field work possible.

[2]Fifteenth Census of the United States, 1930. Horticulture, p. 31.

[3]Anonymous. Carnation diseases. (Summary of lecture delivered by A. F. Woods before the Washington Florists' Club on February 6, 1906.) Florists' exch. and hort. trade world **21**[8]: 239. Feb. 24, 1906.

States Alternaria blight has been recognized[4] in four provinces of Canada, in Brazil, and in England, Germany, Italy, and Bulgaria. It probably occurs wherever carnations are grown.

ECONOMIC IMPORTANCE

Alternaria blight is probably the most prevalent and serious disease of carnations in the United States. The writer has observed it every year during the period 1937–1940, inclusive, in varying degrees of severity in a majority of the greenhouses visited, particularly on Long Island. Many growers speak of it as "the disease" of carnations. Guba (10) has described it as one of the most serious obstacles to the successful culture of carnations in Massachusetts.

Plants in the field are sometimes affected by Alternaria blight to such an extent that they are worthless for benching purposes. Leaf infections initiated in the field, which are not particularly evident at the time of benching, frequently result in the death of large numbers of leaves after benching. Such plants, which appear green and healthy when they are brought in from the field, often are dry and dead two or three weeks later. Even in the absence of an epiphytotic, many of the lower leaves are killed by the disease each year.

Stem infections, when occurring at the base of the main stem, usually cause the ultimate death of the entire plant. Such infections often become evident in large numbers just prior to, or shortly after, benching. Similar infections in the lateral branches also appear commonly throughout the season, and these result in the weakening and final death of branches and their potential side shoots.

In contrast to neighboring healthy plants, affected plants suffer a very noticeable check in growth, with a resulting delay and reduction in flower production. Evidence presented in table 8 shows that, in a season favorable for the disease, the flower production of very susceptible varieties may be halved. Statistics are not available to show the loss from Alternaria blight in the United States in any particular year, but it is probably very large.

SUSCEPTS

PLANTS AFFECTED

Reports in the literature of the occurrence of Alternaria blight on the genus Dianthus are largely confined to *D. caryophyllus* Linn. Christoff (3) reported finding spots caused by *Alternaria Dianthi* Stev. and Hall on *Dianthus tristis* Vel. in Bulgaria. Clemente (4) obtained infection on *D. barbatus* Linn. by artificial inoculations with the pathogen. Inoculations made by the writer with conidia of *A. Dianthi* have confirmed the results of Clemente and extended the list of Dianthus suscepts to include *D. plumarius* Linn., *D. chinensis* var. *Heddewigii* (Linn.) Regel, and × *D. Allwoodii* Hort. (figure 2). None of the species inoculated was immune, which indicates the probable susceptibility of numerous other species of this genus. On several occasions lesions have been observed on *D. barbatus* and

[4]Information kindly furnished by Dr. H. A. Edson of the Division of Mycology and Disease Survey of the United States Department of Agriculture, from a survey of the literature made by Miss Woods of his staff.

D. chinensis in gardens. From these lesions an unidentified species of Alternaria was readily isolated.

In the absence of extensive tests, little is known concerning the range of suscepts other than species of *Dianthus*. Chaudhuri (2) reported a serious wilt disease on *Hibiscus tiliaceus,* Jasminum and marigold in India, which he attributed to *A. Dianthi* Stev. and Hall. He described no reisolations or inoculations on carnations, however.

VARIETAL SUSCEPTIBILITY

Various authors have claimed marked differences in the susceptibility of carnation varieties to Alternaria blight (13) (15) (16) (18) (19) (24) (27) (28). Observations have shown that a majority of the varieties grown on Long Island are equally susceptible, although many commonly appear to escape infection.

Of 73 varieties, Guba (19) listed 36 as being resistant, 10 slightly susceptible, 6 moderately susceptible, and 21 very susceptible. Of these 36 resistant varieties, Chief Kokomo, Ivory, My Love, Patrician, Sophelia, Maine Sunshine, Pink Abundance, Mrs. M. Beuerlein, Bonanza, Orchid Beauty, and Woburn are common on Long Island. Systematic observations made by the writer in the greenhouses of ten growers following the wet season of 1938 appeared to warrant the classification of all these varieties, except Woburn, as being moderately to very susceptible. Subsequent inocu-

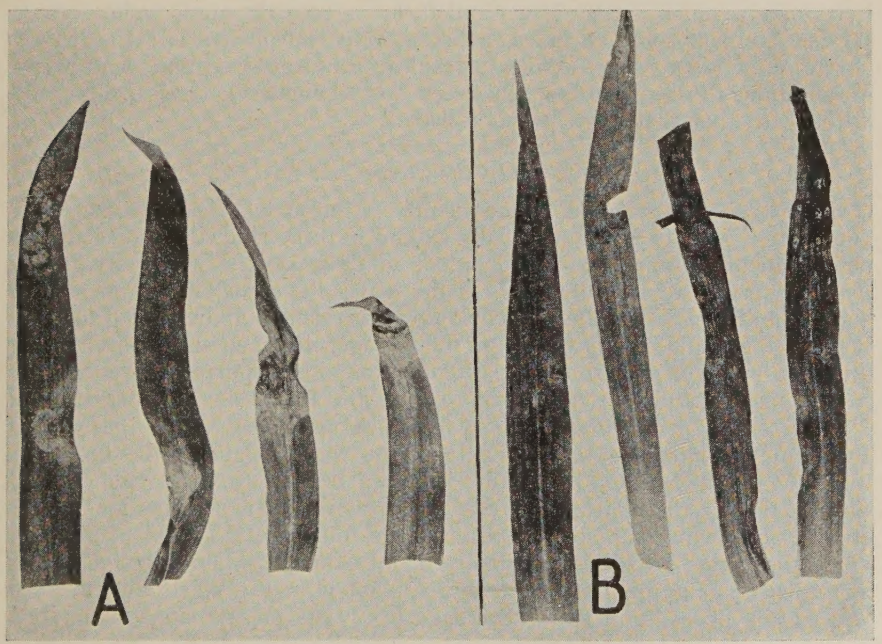


FIGURE 1. ALTERNARIA BLIGHT ON LEAVES OF COMMERCIAL CARNATIONS (*Dianthus caryophyllus* LINN.)
(A) Naturally inoculated.
(B) Artificially inoculated with conidia.

lations under controlled conditions of the first five of the above eleven varieties demonstrated a high degree of susceptibility. But very limited observations on Woburn were made.

The usual escape from infection, under ordinary field conditions, of such a variety as Maine Sunshine may be due to some klendusic factor or factors, such as wettability of the leaf surface. On the other hand, the possibility of the existence of pathogenetic races of *A. Dianthi* must not be overlooked in accounting for observational differences on a given variety in various locations.

SYMPTOMATOLOGY

MORPHOLOGIC SYMPTOMS

The symptoms of Alternaria blight are manifested chiefly on the leaves (figures 1 and 2) and stems (figure 3), but lesions on the flowers also occur.

On the leaves

Infections which develop on either surface of a leaf are first evident as tiny purple spots less than one-half millimeter in diameter. These minute lesions soon develop a broad, yellow-green border which is particularly noticeable in transmitted light; later, as the more or less circular spots enlarge, a small light-brown to greyish, necrotic shrunken spot appears in the center. With further enlargement the necrotic center becomes proportionately much larger, surrounded by a narrow outer yellow-green border, and, on some varieties, a broad inner purple border. Frequently several expanding lesions coalesce, resulting in large, irregular dead areas. In addition, the healthy tissue between spots commonly turns yellow and withers, so that the entire leaf is killed.

On the stems

Stem infections originate in the vicinity of the nodes. Leaf lesions occurring at the base of the leaves usually extend into the stem internodes. Spots similar in appearance and development to those on the leaves frequently develop on the stems in the axils of the leaves. The coalescence of several such minute lesions produces a canker which extends above and below the node on the stem. These cankers on the younger green stems usually exhibit an ashen-white or greyish center, often delimited by a purple border. As the lesion enlarges and ages, the surface of the affected tissue becomes sunken.

Stem lesions are at first confined to the outer tissues and to one side of the stem, but later they usually extend into the pith and girdle the stem. The affected stem tissue is sharply delimited from the neighboring healthy tissue, and has the appearance of a dry brown rot. In conjunction with a stem lesion, symptoms soon appear on the foliage. All shoots originating above the canker are ultimately involved; for example, when infection occurs at the base of the main stem, the entire plant is finally killed. A one-sided effect often prevails, in that the foliage or shoots on the side of the stem where the canker appears are the first to exhibit the symptoms. Such shoots are dwarfed and seldom grow much after the stem lesion develops. The center terminal, followed shortly by the outer terminal leaves of an affected shoot, first becomes light-green in color and frequently develops a peculiar

mottled appearance (figure 3). This mosaic-like effect is very characteristic, and, to the writer's knowledge, has not heretofore been recorded. Gradually these and the remaining leaves of the shoot turn yellow. Wilting and subsequent death follow.

On the flowers

Flower infections sometimes occur on the calyces and are comparable to those which develop on the leaves. They are ordinarily of slight concern in commercial ranges, however, because the flowers are cut during a period when conditions are unfavorable for Alternaria-blight infection to occur.

ETIOLOGY

Alternaria blight of carnations is caused by the fungus *Alternaria Dianthi* Stevens and Hall. Association of a species of Alternaria with the disease was first noted by Orton (25) in 1905. In 1909, Stevens and Hall described and named the pathogen. They stated that only one other species, *A. longispora McAlph.,* had been reported on a member of the Caryophyllaceae, and this failed to agree in size, shape, or septation of its spores with *A. Dianthi.* In 1928 Corbett (6) described a disease essentially similar to Alternaria blight which he claimed was caused by an Alternaria species morphologically unlike *A. Dianthi.* Claims similar to those of Corbett were made by Clemente (4) in 1940.

Stevens and Hall (28) described the conidia of *A. Dianthi* as being catenulate, clavate, tapering, base obtuse, dark brown, slightly constricted at the septa, transverse septa 5–9, longitudinal septa 0–5 and measuring 26–123μ × 10–20μ. Corbett (6) pointed out that the conidia of the species he studied were shorter and wider, measuring 26–103μ × 13–38μ. Overholts (26) stated that, in material of *A. Dianthi* which he examined, the conidia were shorter than those of Stevens and Hall, measuring 45–72μ × 12–19μ and were rather characteristic in being narrower than in most species. Similarly, Clemente (4) reported variation from the original description of *A. Dianthi* in that in his material the conidiophores and conidia were ochraceous rather than dark brown, the conidia had a well developed foot, and measured 20–184μ × 8–20μ with 1–12 transverse septa, an occasional single, longitudinal septum, and one or two oblique septa.

Twelve specimens of the pathogen on diseased material from Missouri, Illinois, New York, and Massachusetts have been studied by the writer. This examination has shown a wide variation in shape, size, and septation of spores. The range in the latter two characteristics, even in specimens from various sections of Long Island, includes measurements of 20–123μ × 9–36μ with 2–13 transverse and 0–3 longitudinal or oblique septa. This range is illustrated in figure 4. Isolates of the fungus showing similar variation, and including some of the above specimens, have all proved to be pathogenic. Present evidence does not warrant assuming the existence of more than one species of this pathogen.

Although no perfect stage has as yet been definitely associated with it, Passalacqua (27) reported finding perithecia of a species of Pleospora, presumably *Pl. herbarum,* and Christoff (3) observed perithecia of a new species of Leptosphaeria on lesions caused by *A. Dianthi,* the former on *Dianthus caryophyllus,* and the latter on *D. tristis.* In these two cases proof was lacking of a definite connection between the perfect and imperfect stage.

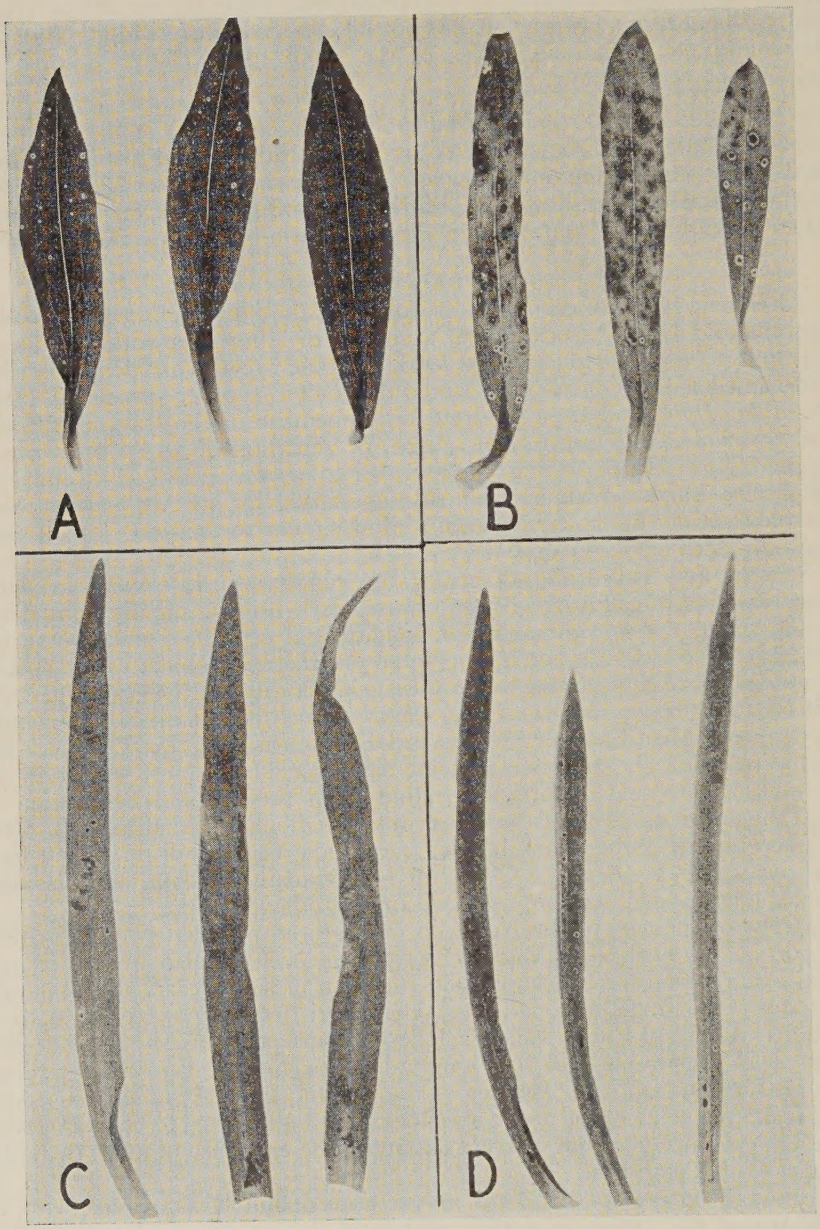


FIGURE 2. ALTERNARIA BLIGHT ON LEAVES OF VARIOUS DIANTHUS SPECIES 5 DAYS AFTER INOCULATION WITH CONIDIA OF *A. Dianthi*

(A) *D. barbatus* Linn.
(B) *D. chinensis Heddewigii* (Linn.) Regel.
(C) × D. *Allwoodii* Hort.
(D) *D. plumarius* Linn.

PATHOGENICITY

The ability of *Alternaria Dianthi* to produce infection on carnations was first demonstrated by Stevens and Hall (28). They described several inoculations in which bits of agar bearing mycelium and spores, and also drops of a spore suspension, were placed in the axils of leaves. In a humid atmosphere infection resulted in most cases, with or without the presence of wounds, although apparently no re-isolations of the pathogen were made.

Numerous successful inoculations on leaves and stems have been made by the writer in further carrying out the rules of proof of pathogenicity. In all cases the uninoculated check plants remained free of infection. Various isolates of the pathogen, obtained from infected leaf and stem tissue, all proved to be pathogenic under suitable environmental conditions. In the absence of wounds, high humidities were found to be essential, as pointed out by Stevens and Hall. The use of conidia from potato-dextrose agar cultures held at room temperatures for 20–30 days also gave more uniform results than the use of older spores from this source, because conidia in cultures older than this often appeared to have lost their virulence. Furthermore, when inoculations were made by atomizing plants with spore suspensions, the use of a 1–500 gelatin solution in making up the spore suspension considerably improved the adherence of the drops to the foliage and the uniformity of results obtained.

Typical leafspot and stem-canker symptoms were readily produced as a result of the inoculations described above. In connection with the latter type of infection, however, the foliage symptoms were generally of the yellowing, followed by wilting, type. For some unknown reason, the characteristic leaf mottling effect (figure 3) which usually precedes yellowing developed on only a very small percentage of the plants which were inoculated in or on the stems.

In addition to carnations, two series of successful inoculations with an isolate of *A. Dianthi* pathogenic to carnations were made on seedlings of *Dianthus barbatus, D. plumarius, D. plumarius scoticus, D. chinensis Heddewigii,* and × *D. Allwoodii* Hort., which were approximately five months old at the time of inoculation. Successful re-isolations were made from lesions on the inoculated plants at the end of a week.

LIFE HISTORY OF THE PATHOGEN

SOURCES OF INOCULUM

Infested and infected cuttings and rooted plants

Observations in greenhouses have shown that primary Alternaria-blight infections are frequently initiated in the cutting bench. Kirby (21) reported that 60.5 per cent of a lot of cuttings in sand developed infection under natural conditions. Guba (8) (13) (16) suggested that conidia of *A. Dianthi* may be introduced to the cutting bench on the foliage of infested cuttings. This theory has been confirmed by the writer by examining, with the aid of a Leitz "Ultrapak" microscope, leaf surfaces of healthy cuttings taken from infected plants. Additional evidence was obtained by atomizing similar cuttings with sterile water, after which they were placed under a moistened bell jar for several days. Many leafspots appeared on these cuttings.

Furthermore, although conditions during the winter and early spring ordinarily appear to be unfavorable for the development of new infections on the foliage of mature plants, lesions are often observed on cuttings taken during this period. Consequently, the spores present on such lesions may serve as a source of inoculum for new infections in the cutting bench, as observations indicate.

In a like manner the conidia developing on early primary lesions in the cutting bench provide inoculum for secondary infections; and these in turn produce spores for a series of subsequent secondary infections in the greenhouse and field. Germination tests made with conidia taken from lesions on young plants later planted in the field have demonstrated high germinability.

Infested soil

The somewhat common practices of growing carnations for two or more consecutive years on a given piece of land and strewing old carnation debris in the field raise the question as to whether or not the pathogen persists in the soil and thus serves as a source of inoculum. In this connection, Guba (12) (13) (16) claims that *A. Dianthi* survives one, but not two winters in the field. Overwintering experiments conducted on Long Island, in which pure cultures of the pathogen growing in sand-wheat-water medium, in milk bottles, and glass vials were buried in the soil, gave negative results in attempting to recover the fungus from the overwintered cultures. In an additional test, infected sporulating leaves, placed in wire baskets, were left in the field during the winter of 1938–39. A majority of these spores, which showed 85 to 90 per cent germination in September, 1938, were no longer viable in April, 1939, although a few produced weak germ-tubes in tap water on glass slides at room temperature. Although the production of secondary spores by such germ-tubes was not observed, it may occur. Further, there remains the possibility that overwintering mycelium may produce spores the following spring.

On the assumption that the pathogen may overwinter in the field, control experiments were conducted in which plants were grown in old carnation land and in new virgin land during the summer. In the first of these experiments, conducted in 1938, a large bed of each of the varieties Joan Marie and Patrician was grown in old land and in new land. Toward the end of July, counts were made of the number of leafspots on 50 plants selected at random in each bed. Calculations from these data showed that the average number of leafspots per plant on old and new land plots was respectively 38.5 and 39.7 in the case of the variety Patrician, and 125.0 and 118.3 on the variety Joan Marie. The results from a replicated, factorial design experiment (table 6) confirm the above results in showing no significant difference in the amount of infection developing on old and on new land.

The appearance of infection on plants grown in new field soil is explained by the carry-over of inoculum from the greenhouse as discussed above. The introduction of such inoculum to the field appears to minimize the importance of possible field inoculum. In the event that greenhouse inoculum is not present, however, the possible existence of viable field inoculum should not be overlooked, as observations indicate. From the data in table 6, an apparent trend is evident toward greater infection on old land. Furthermore, observations made in a similar experiment, conducted in 1940 for

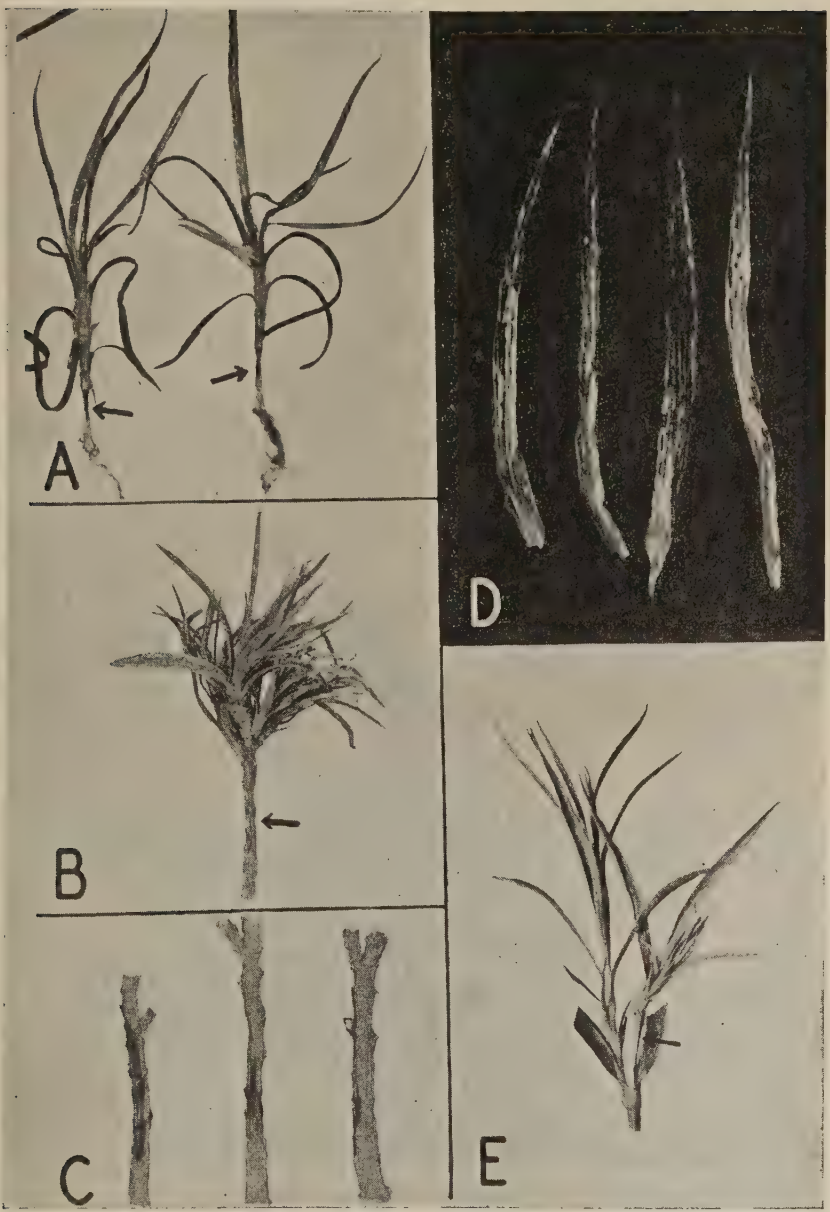


FIGURE 3. SYMPTOMS ASSOCIATED WITH ALTERNARIA STEM CANKERS

(A) and (B) Stunted young plants of the variety Virginia with basal stem cankers (arrows) showing crippled and mottled terminal leaves. The stems in (A) were cut longitudinally.

(C) Longitudinal cuts through cankered stems showing the dry, brown rot.

(D) Mottled or chlorotic terminal leaves.

(E) A sporulating canker (arrow) on a lateral shoot.

the control of Fusarium yellows, indicated that considerably greater Alternaria infection developed on plants of the variety My Love grown in old land than on those grown in new land.

INOCULATION

The most important single agent in disseminating conidia of *Alternaria Dianthi* is probably water. This was suggested by Guba (10) (15). The splashing drops of water from rain in the field and from syringing and watering in the greenhouse carry the spores to the infection courts. Guba (15) claimed that a spray for red-spider-mite control containing 5 per cent salt and 0.2 per cent nicotine sulfate may also serve in this capacity. The role of wind as a disseminating agent has not been investigated by the present author, but in a popular article Guba (13) stated that the spores of this pathogen are "not wind-carried or at least they are not carried far."

In attempts to determine the ability of water to disseminate conidia of the pathogen three methods were used as follows: (1) distilled water was pipetted over a sporulating lesion and several drops were caught separately; (2) rain droplets were collected from apparently healthy leaves of infected plants; and (3) infected plants were artificially sprinkled and the run-off water caught in small watch glasses suspended among the branches of the plants. Microscopic examinations of the water droplets collected in the above three ways revealed the presence of numerous Alternaria conidia. Although no attempt was made to demonstrate their pathogenicity, it may be safely assumed that a large majority of the Alternaria conidia were those of *A. Dianthi*. In one instance a collection of the spores was incubated for 8 hours, and it was found that 95 per cent had germinated, thus leaving no doubt as to their viability.

INFECTION COURTS

Stevens and Hall (28) described successful inoculations in the axils of the leaves in the presence or absence of wounds. It is not clear from their account, however, whether infection developed on the leaves, on the stem, or both. Corbett in 1928 obtained leafspot infections by atomizing apparently uninjured leaves with a spore suspension of an Alternaria species. Guba (12) (13) claimed that, although injuries to the leaves are not essential for infection to occur, the injuries made by red-spider mites, spray materials, or artificially with the needle and knife, provide favorable infection courts. Clemente (4) observed that usually the germ-tubes penetrate directly through the epidermis but occasionally enter through stomata.

Leaf infections

With the aid of a Leitz "Ultrapak" microscope the writer made numerous observations of germ-tube penetration and in all instances penetration occurred through the stomata. This point was confirmed by examinations of cross-sections of infected leaves.

Inoculations of artificially wounded leaves verified the observation that injuries or abrasions serve as excellent infection courts because it was found that infection proceeds at a more rapid rate than in the absence of wounds. The above facts strengthen the observation of Guba (12) that under

greenhouse conditions infections commonly occur on the cut ends of pruned cuttings.

Stem infections

The initiation of stem infection was demonstrated by pipetting a spore suspension into the axils of apparently uninjured leaves and upon young stem internodes. Presumably, the infections, evidenced as small spots similar to those which occur on the leaves, resulted from germ-tube penetration through stomata or lenticels. Individual infections remained small, shallow, and undeveloped even when the plants were kept in moist chambers over an extended period. When several stem lesions were close together, however, as in the leaf axils, their coalescence under humid conditions resulted in the development of a typical stem canker. Control plants similarly inoculated with drops of sterile water remained healthy.

Inoculations showed also that, under humid conditions, stem cankers may result from the continued expansion of leaf lesions into the stems.

Lesions on woody stems were readily obtained in a moist atmosphere, when inoculum was applied to wounded surfaces or when artificially infested soil was packed around the wounded bases of plants. In no cases were infections obtained following various inoculations on unwounded woody stem tissue.

The results discussed above agree with field observations on the origin of stem infections. Under natural conditions drops of water, often carrying conidia, commonly collect in the leaf axils. Here the spores germinate and the germ-tubes enter either the injured or uninjured stem or leaf base, resulting in the formation of stem cankers. Likewise, an enlarging leafspot may extend down into the stem with a similar result. Presumably, cankers which are frequently evident in advanced stages in the woody part of the main stem are caused either by one of the above means before the stem becomes woody, or by wounds which are often observed as growth cracks or mechanical injuries in the woody tissue.

INCUBATION

The effect of temperature

On the rate of spore germination. Three trials were conducted with conidia taken from cultures 20 to 25 days old, of 2 isolates of *A. Dianthi* growing on potato dextrose agar. Using the technique of McCallan (23), the conidia were incubated at various temperatures and after certain intervals they were examined for germination.

Apparently, from the data in table 1, spore germination occurred at temperatures covering a wide range (approximately 37°–88° F.), but the rate of germination was considerably reduced toward the extremes. Germination occurred most rapidly in temperatures ranging from 64° to 81° F., with the peak at approximately 75° F. In this optimum range, germ-tube formation was evident after 4 hours, and the majority of the spores had germinated in 8 hours. Spores from cultures 50–60 days old appeared to germinate in fewer numbers and considerably more slowly than younger spores from a similar source.

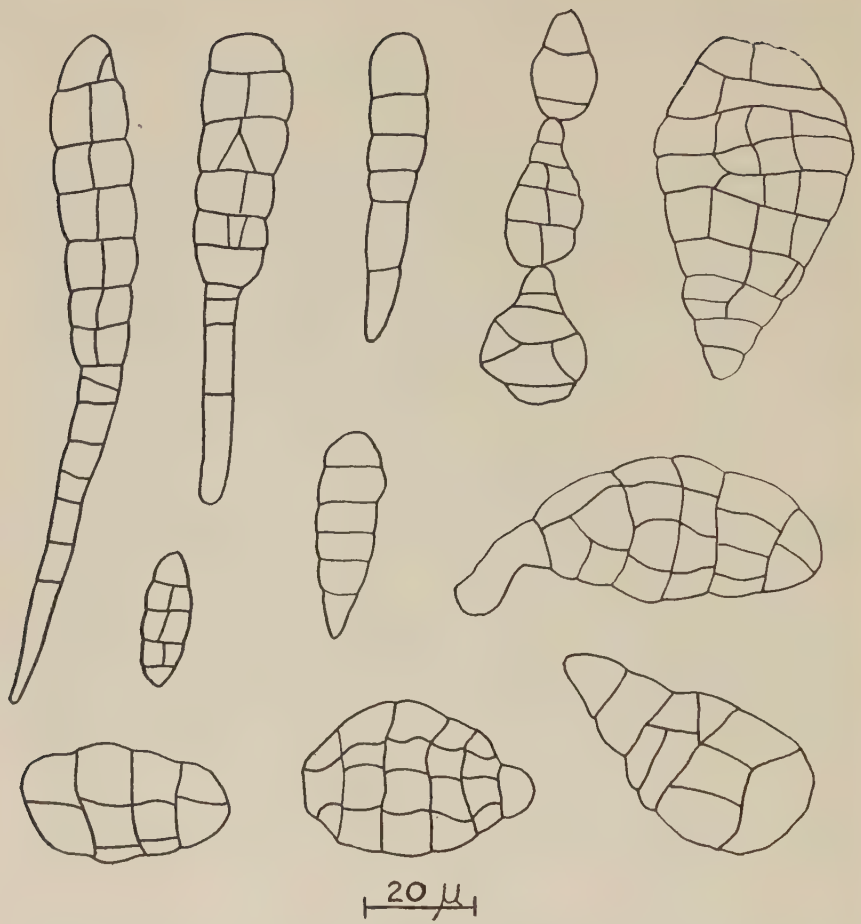


FIGURE 4. CONIDIA OF *A. Dianthi* FROM VARIOUS DISEASED SPECIMENS SHOWING TYPICAL VARIATION IN SHAPE, SIZE, AND SEPTATION

Drawings made with the aid of a camera lucida.

On the length of the incubation period. The results of numerous inoculation experiments on leaves at ordinary room temperature and at greenhouse temperature have indicated that the length of time required from inoculation until the first visible evidence of infection varied from twenty-four to forty hours. Two experiments were conducted to determine the length of this period at various temperatures. In each test young potted plants of the variety Patrician were atomized with a spore suspension of conidia, from potato-dextrose agar cultures 25 to 30 days old, in a 1–500 gelatin solution. Five plants were then placed under moistened battery jars in each of several incubators at various temperatures. After twenty hours the plants were examined at frequent intervals for evidence of infection.

TABLE 1. EFFECT OF TEMPERATURE ON THE RATE OF GERMINATION, IN WATER ON GLASS SLIDES, OF 20- TO 25-DAY-OLD SPORES OF *Alternaria Dianthi* FROM POTATO-DEXTROSE AGAR CULTURE

Time interval (in hours)	Range of temperature (degrees F.)										
	36.5 to 37.4	39.2 to 44.6	45.5 to 48.2	50.0 to 51.8	55.4 to 61.7	64.4	66.2 to 68.9	74.3 to 75.2	80.6	80.6 to 88.0	92.3 to 93.2
	Per cent germination in indicated interval										
4	0	0	0	0	0	1.0	2.0	9.1	3.6	0	0
8	0	0	8.0	13.5	65.7	76.4	73.1	83.6	80.4	59.8	0
12	0	19.1	49.3	72.0	81.7	89.3	89.3	95.2	92.0	71.1	0
16	0	23.6	70.1	82.1	91.4	96.9	95.5	96.9	96.2	85.1	0
20	0	32.3	90.5	91.0	96.3	...	...	...	...	93.0	0
24	5.7	71.2	95.1	96.8	...	...	...	...	...	95.4	0
31	8.0	81.1	...	...	...	...	...	...	...	95.6	0
36	23.9	85.7	...	...	...	...	...	...	...	...	0
40	34.4	94.2	...	...	...	...	...	...	...	...	0

It is assumed that the temperature changes resulting from these examinations were of slight concern. The results (table 2) show that within a range of

TABLE 2. LENGTH OF INCUBATION PERIOD OF ALTERNARIA LEAFSPOT INFECTIONS AT VARIOUS TEMPERATURES IN THE VARIETY PATRICIAN

Temperature range (degrees F.)	Length of incubation period (hours) (range of 2 trials)
34.0–38.0	No infection
45.5–48.2	70–72
55.4–60.8	47–70
66.2–68.7	28–28.5
78.8–80.6	28–28.5
80.6–86.0	28–34
89.6–92.3	No infection

approximately 67° to 81° F., the incubation period is about 28 hours, and is proportionately longer at higher or lower temperatures. This agrees, on the whole, with results on the rate of spore germination at various temperatures (table 1).

The effect of temperature on the length of the incubation period in the case of wound inoculations on leaves and stems was not investigated. In the various inoculations made, however, visible symptoms of infection around the wounded area appeared in 24 to 48 hours at greenhouse temperatures ranging from approximately 65° to 80° F. Under these conditions, foliage symptoms in connection with stem cankers became evident 10 to 60 days after inoculation. Corbett (6) claimed that wilting of the foliage on stems inoculated with an Alternaria sp. appeared from 11 to 61 days after inoculation, depending on the time of year and the age of the plants.

On the amount of infection. Using the technique of Lyle (22) experiments were conducted in an attempt to correlate the amount of infection occurring at various temperatures, and the period of contact with moisture required by the conidia. Potted carnation plants of the varieties Joan Marie and Patrician were atomized with a gelatin suspension of spores from 20- to 25-day-old cultures until all the leaves were thoroughly wet. The plants were then placed under moist chambers in incubators at various tempera-

tures. At the intervals shown in table 3, one plant was removed from each chamber and the leaves thoroughly dried. Precautions were taken to keep water off the foliage of these plants in the greenhouse for four days and then the number of leafspots on each leaf was counted. The average number of spots per leaf from the various trials is shown in table 3.

It was not certain in these experiments that uniform amounts of inoculum were applied to each leaf. The results from the various trials were consistent, however, and agree in showing that, in the presence of satisfactory moisture conditions, infection will occur at a wide range of temperatures, extending from approximately 46° to 86° F. This is well within the range of field and greenhouse temperatures on Long Island. The optimum appears

TABLE 3. THE RELATION OF TEMPERATURE AND PERIOD OF WETTING OF CONIDIA OF *Alternaria Dianthi* TO THE NUMBER OF LEAF INFECTIONS ON THE VARIETIES JOAN MARIE AND PATRICIAN

Length of time foliage was wet (hours)	Number of trials	Range of temperature observed (degrees F.)							Total lesions excluding those at temperature range 84.2° to 86.0°
		34.7 to 40.1	45.5 to 48.2	55.4 to 64.4	66.2 to 69.8	78.8 to 80.6	84.2 to 86.0	87.8 to 93.2	
		Average number of lesions per leaf (calculated)							
6	2	0	0	0	0	0	....	0	0
8	3	0	0	0	0.14	0	0	0	0.14
9	1	0	0	0.27	0.27	0	....	0	0.54
10	4	0	0	0.05	0.39	0.67	0.37	0	1.11
12	5	0	0	0.20	0.58	1.53	0.12	0	2.31
14	2	0	0	0.35	7.00	3.50	....	0	10.85
16	2	0	0	1.55	9.85	6.65	....	0	18.05
18	1	0	0	2.55	12.20	10.68	....	0	25.43
24	2	0	0.10	7.00	9.65	10.69	....	0	27.44
36	2	0	1.41	13.30	14.61	13.80	....	0	43.12
48	2	0	2.82	24.43	26.30	26.11	....	0	79.66
Total		0	4.33	49.70	80.99	73.63	....	0	

to lie in the neighborhood of 70° F. and, particularly below this temperature, a longer period of wetting of the spores seems necessary for infection.

The above results are in fairly close agreement with those obtained on the rate of spore germination at various temperatures (table 1). From limited observations it appears that a higher optimum temperature is necessary for lesion enlargement than for spore germination and the initiation of infection. As pointed out by Guba (14), the optimum temperature for growth of the fungus in culture is approximately 80° F., which correlates with the above observations.

The effect of period of wetting

The results shown in table 3 also illustrate the effect that various periods of contact of the conidia with water have on the initiation of leaf infections. Within the range of these tests, the amount of infection increased in proportion to the period of wetting of the leaf surfaces; this was apparently due to the proportionate increase in the number of spores which germinated. In a temperature range of approximately 60° to 80° F., it appears that moisture must be in contact with the conidia for a minimum period of 8 to 10 hours for infection to occur.

From these data it is obvious that water, the principal agent of inoculation, favors spore germination and infection. As early as 1906 Woods[5] called attention to the effect of a wet environment on the incidence of Alternaria blight and this relationship between the environment and the disease has been repeatedly pointed out in the literature, (7) (8) (12) (13) (14) (16) (17) (19) (28). Rain and dew periods in the field, and splashing water in the greenhouse, that keep the foliage wet for at least 8 to 10 hours, provide conditions necessary for infection. The actual humidity requirements of the pathogen for spore germination are not known with certainty. Attempts to germinate conidia on dry slides in moist chambers, however, have shown that germination occurs at a much slower rate than when the spores are actually in contact with water. No provisions were made in these tests, however, to prevent condensation of moisture on the slides caused by temperature fluctuations. It has been demonstrated that spore production by the pathogen occurs only in a humid environment. Furthermore, in the presence of high atmospheric humidities, water on the foliage will probably evaporate at a reduced rate.

CONTROL

MANIPULATION OF CULTURAL PRACTICES

Field versus greenhouse growing

Numerous observations on Long Island have shown that Alternaria blight is serious only on plants grown in the field during the summer, as plants maintained in the greenhouse throughout the season remain practically free of the disease. This was pointed out as early as 1906 by Woods[6] and confirmed later by Guba (13) (15) (19). Such factors as high prevailing day-temperatures and the absence of a long period during which the foliage remains wet probably account for the lack of development of secondary infections in the greenhouse during the summer.

The average number of leafspots per plant, calculated from records taken August 1–3, 1940, in a replicated factorial design experiment, is shown in table 6. Considerable infection developed on the field-grown plants, whereas none appeared on the greenhouse-grown plants, whether the latter were or were not sprayed with bordeaux mixture. This difference is highly significant and corroborates results of previous experiments. Records of flower production, per square foot of bench, from greenhouse and from field-grown plants, in a wet season favorable for infection in the field (table 8), show that plants of very susceptible varieties kept in the greenhouse throughout the season may produce more than twice as many flowers as those grown in the field during the summer.

Care in watering

The introduction of D-N dust[7] and its well established efficiency in red-spider-mite control on carnations, according to Blauvelt and Bickerton (1), have made syringing unnecessary. Many growers, however, with the thought of assisting recovery from transplanting, still water overhead, particularly during the critical period for infection immediately following benching from

[5]See footnote 3, p. 3.
[6]See footnote 3, p. 3.
[7]D-N dust consists of one per cent dinitro-orthocyclohexylphenol diluted with dusting sulfur.

the field. Guba (10) (14) (15) (19) without presenting evidence, has repeatedly pointed out the effect of syringing in spreading Alternaria blight. He presented indirect proof (12), however, in stating that the use of naphthalene fumigation in place of syringing for red-spider-mite control resulted in a 27-per-cent increase in flower production.

The effect of syringing in spreading Alternaria blight in the greenhouse was shown in an experiment conducted in 1937. On July 23 a section of a bench of the variety Joan Marie was divided into four plots, each containing approximately 450 plants. These plants were severely infected with the disease. Each alternate plot was syringed once or twice a day for two weeks. The remaining two plots were watered at soil level during the two-week period. At the beginning of the experiment 30 plants spaced at regular intervals in each plot were marked and counts made of the total number of leafspots on each plant. On August 6 a second count was made on these plants. Calculations made from these data show that the average number of leafspots per plant increased during the two-week period from 16.0 to 43.8 in the syringed plots and from 12.3 to 21.2 in the unsyringed plots. A statistical analysis[8] of these data shows that syringing increased the disease much more than ordinary watering, the difference being highly significant.

Numerous observations in greenhouses have shown that considerable splashing of water and wetting of foliage often occur in watering, even when syringing is not practiced. This would partly explain the increase in infection in the above nonsyringed plots. Furthermore, some lesions which were not visible at the first count probably matured and were recorded in the second count. If water remains on the foliage for a period of 8 to 10 hours, infection will result when the pathogen is present. It is a common belief that wetting of the foliage can be safely accomplished on the morning of a bright day. That this is not always true was shown by observations made on infected plants, in a well ventilated, commercial range, which were syringed in the morning of a bright windy day in August, 1940. Water was still evident on the foliage of these plants in the evening, and the following day numerous new leaf infections became evident.

Early versus late benching

Guba (16) presents evidence to show that plants transplanted from the field July 15 produced three times as many flowers as those benched August 10, presumably due to a greater amount of Alternaria-blight infection on the later-benched plants. It has been commonly observed on Long Island that the longer plants are left in the field exposed to rain and dew periods, the more they become affected with the disease.

Further evidence in favor of early benching was obtained in an experiment conducted in 1939. Field-grown plants of the variety Virginia, all of the same age, were planted in a greenhouse bench divided into 24 equal plots. Twelve of these plots, selected at random, were planted June 17, and the remaining twelve on July 24. Calculations from counts made September 14 in each plot show that an average of 8.58 shoots affected with Alternaria stem canker developed in the early benched plots and 27.75 in the late

[8]All statistical treatments of data in this text were made by the analysis-of-variance method.

benched plots. A statistical analysis of these data shows that the increase in infection by benching July 24 as compared with June 17 is highly significant.

APPLICATION OF FUNGICIDES

Bordeaux mixture for the control of Alternaria blight of carnations was recommended as early as 1906 by Woods.[9] Since then Guba (8) (9) (10) (11) (12) (13) (14) (15) (16) (19) (20) has discussed the results of numerous laboratory and field tests conducted with various fungicides. Although most details of these experiments are lacking, Guba concluded that the best results are obtained by spraying field-grown plants with bordeaux mixture to which is added one pound of calcium arsenate and a suitable spreader such as linseed oil, fish oil, or Penetrol[10] at the rate of 1 part in 800 parts of the spray (16) (20). He questioned the value of spraying plants which are benched by July 15 and recommended this means of control only for plants left late in the field (16) (19).

Comparison of fungicides

Several laboratory and field tests have been conducted by the writer in comparing the efficacies of various copper fungicides, including bordeaux mixture, and sulfur fungicides. Bordeaux mixture proved superior, particularly in the field, to all other materials at the concentrations tested. Sulfur dust showed considerable promise in preliminary field trials, but, in a season favorable for infection, was found to be inferior to bordeaux mixture 4–4–50 plus Penetrol 1–600 (table 7). The data show that the mean difference in infection, following applications of the two fungicides, is highly significant in favor of bordeaux mixture.

Laboratory tests with various concentrations of copper sulfate and lime in bordeaux mixture showed no significant differences in inhibition of conidial germination on glass slides. In field comparisons, however, a 4–4–50 mixture was used for the sake of uniformity. In other spore germination tests, calcium arsenate, at a concentration of one pound to 50 gallons of water, exhibited very slight toxicity to conidia of the pathogen. Likewise, the addition of this material in the above concentration to bordeaux mixture 4–4–50 did not improve the ability of the latter to inhibit spore germination in comparison with bordeaux mixture 4–4–50 alone.

Comparison of spreaders

The necessity of adding a spreader to bordeaux mixture for spraying carnations was pointed out in 1907 by Woods (29). Laboratory tests were made in 1938 with a large number of spreading and wetting agents. The ability of various concentrations of these materials, incorporated in bordeaux mixture 4–4–50, to "flatten out" drops of the mixture on carnation leaves was determined. On this basis six spreaders, listed in table 4, were selected for comparison in the field with bordeaux mixture alone. In addition, a 20–80 copper-lime dust, applied in the early morning when dew was present on the foliage, was included in the test. For this experiment, three contiguous beds in the field, one of each of the varieties Joan Marie, Sophelia, and

[9] See footnote 3, p. 3.
[10] Penetrol is an oxidized petroleum-oil product.

Patrician, were divided into 36 equal plots, each containing 60 plants. Four replications of each of the nine treatments were then randomized in the same order on each bed. Seven applications of each treatment were made at 9- to 11-day intervals from May 3 to July 6. Counts were made from July 14 to 19 of the total number of leafspots on twelve plants selected at random in each plot. From these figures the average number of leafspots per plant in each treatment for each variety and the mean for all varieties were calculated (table 4).

TABLE 4. COMPARATIVE SPRAY TREATMENTS FOR THE CONTROL OF ALTERNARIA BLIGHT IN THE FIELD, 1938

Treatment	Concentration	Average number of leafspots per plant			Mean*
		Variety Patrician	*Variety Joan Marie*	*Variety Sophelia*	
1. Check untreated	.....	34.51	68.01	50.70	51.08
2. Bordeaux mixture alone	4–4–50	10.85	20.24	19.66	16.92
3. Bordeaux mixture plus Penetrol 1–800	4–4–50	4.54	7.02	6.56	6.04
4. Bordeaux mixture plus sodium oleyl sulfate 1–400	4–4–50	7.78	11.14	9.87	9.60
5. Bordeaux mixture plus cottonseed oil 1–400	4–4–50	7.07	15.91	13.70	12.24
6. Bordeaux mixture plus raw linseed oil 1–400	4–4–50	4.76	11.27	8.26	8.10
7. Bordeaux mixture plus fish-oil soap 1–400	4–4–50	8.85	14.47	14.14	12.49
8. Bordeaux mixture plus potassium-resin soap 1–400	4–4–50	6.47	9.70	8.04	8.08
9. Copper-lime dust	20–80	21.89	40.06	36.05	32.67

*Difference necessary for odds of 19:1 = 7.46 leafspots.
Difference necessary for odds of 99:1 = 10.11 leafspots.

It is apparent from these data that all treatments gave a highly significant reduction in infection in comparison with the check. Likewise, copper-lime dust was decidedly inferior to all other treatments, including bordeaux mixture alone. This inferiority is probably due in part to the spotty formation of dew drops on carnation foliage. Penetrol 1–800, with odds of 99:1, and raw linseed oil 1–400 and potassium resin soap[11] 1–400 with odds of 19:1, in combination with bordeaux mixture significantly reduced infection in comparison with bordeaux mixture alone. The apparent superiority of Penetrol to other materials in this test led to its use in later experiments. Although a 1–800 concentration was used in the above test, further experiments have shown the advantage of increasing the concentration of this material to 1–600.

Determining Where Spraying is Necessary

Experiments were conducted to determine the necessity of spraying plants with bordeaux mixture 4–4–50 plus Penetrol 1–600: (a) in the greenhouse before transplanting to the field, (b) in the field, and (c) after benching from the field.

In a factorial design experiment conducted in 1939, plants were (a) sprayed, or (b) not sprayed, in the above three locations, resulting in eight combinations of these factors. Approximately 1500 plants of the variety Patrician were sprayed at 14-day intervals from the time of propagation until May 1, and an additional 1500 plants of the same variety were not sprayed during this period. On May 8 these two lots of plants were trans-

[11]Potassium resin soap was prepared as outlined by Newton and associates (24).

planted to plots in the field by randomizing the eight multiple treatments, mentioned above, in each of two beds, resulting in two replications of each treatment. Since the plants used in this experiment were propagated at different intervals, the plants of all propagation dates were thoroughly mixed to insure reasonable uniformity of material in each plot, after which random samples of 185 plants were taken.

The plots which were sprayed in the field received seven applications of bordeaux mixture at 10-day intervals, beginning May 5 and ending July 14. On July 18 all plots were transplanted to one bench in the greenhouse by lumping the two field-replications of each treatment so that eight plots were randomized in the bench. Each plot was planted with from 280 to 330 plants. Five applications of bordeaux mixture were made from July 25 to September 4 on the plots to be sprayed after benching. Flower production records were taken on these plots from September 21, 1939, to June 25, 1940, and the number of flowers produced per square foot calculated for each treatment (table 5).

TABLE 5. THE EFFECT OF SPRAYING WITH BORDEAUX MIXTURE 4–4–50, IN THE FIELD AND GREENHOUSE, ON THE CONTROL OF ALTERNARIA BLIGHT AS MEASURED BY FLOWER PRODUCTION (IN VARIETY PATRICIAN), 1940

	Flower production per square foot of bench, Sept. 21 to June 25		Mean*
	Sprayed before transplanting to field	*Not sprayed before transplanting to field*	
Sprayed in field	21.59	19.11	20.35
Not sprayed in field	19.90	18.37	19.13
*Mean	20.74	18.74	
	Sprayed after benching	*Not sprayed after benching*	
Sprayed in field	18.44	22.26	20.35
Not sprayed in field	17.57	20.70	19.13
*Mean	18.00	21.48	

*Difference necessary for odds of 19:1 = 1.20 flowers.
Difference necessary for odds of 99:1 = 2.16 flowers.

In a second factorial design experiment, conducted in 1940, plants of the varieties Joan Marie and Virginia, all of the same age, were (a) grown either in the greenhouse, in the field on old land, or in the field on new land during the summer; (b) sprayed or not sprayed with bordeaux mixture before transplanting; and (c) sprayed or not sprayed during the summer. All combinations of these factors result in 12 treatments.

Early in the season approximately 3000 young plants of each variety were divided into two equal lots in the greenhouse. One lot was left unsprayed, and the other sprayed at 14-day intervals until they were transplanted May 11. At this time the plants were moved to plots in the greenhouse, in the field on old land, and in the field on new land, so that a third of each of the sprayed and unsprayed lots were planted in each location. Two replications of each of four treatments were randomized on two beds or benches of each variety in each of the three locations. These treatments were (1) sprayed before transplanting, sprayed in the summer; (2) sprayed before trans-

planting, not sprayed in the summer; (3) not sprayed before transplanting, sprayed in the summer; and (4) not sprayed before transplanting, not sprayed in the summer. Because these four treatments were also varied according to their location, the twelve possible combinations were thus secured.

From May 20 to July 18 seven applications of bordeaux mixture were made on the summer-sprayed plots. On July 23 all the plots were transplanted to the greenhouse in two contiguous benches of each variety. Twelve plots including all treatments were randomized in each bench, giving two replications of each treatment for both varieties. On August 1–3, counts were made of the number of leafspots on twelve plants selected at random in each plot. Calculations from these records are shown in table 6.

The data from these experiments reveal clearly the necessity of spraying in the field, because a highly significant reduction in infection (table 6) and a significant increase in production with odds of 19:1 (table 5) are shown. This is further substantiated by data from other experiments (tables 4 and 7). There is, however, no necessity for spraying plants maintained in the greenhouse throughout the season, as shown in table 6.

The advantage of spraying before transplanting to, and after benching from, the field is not so clearly demonstrated in the above tests. In table 6 the difference between the greater means (†) for early spraying and no early spraying is not significant; with reference to the lesser means, (*), however, in the absence of field spraying, early greenhouse spraying significantly reduced infection with odds of 19:1, but did not improve the results of field spraying. In 1939, flower production was significantly increased by spraying before transplanting to the field (table 5). It would seem that, in preventing the primary and early secondary infections that develop on the young plants, spraying before transplanting to the field would enhance subsequent control of the disease, particularly in the absence of field spraying.

TABLE 6. A COMPARISON OF THE AMOUNT OF ALTERNARIA BLIGHT ON PLANTS GROWN IN THE GREENHOUSE, IN THE FIELD ON OLD LAND, AND IN THE FIELD ON NEW LAND, SPRAYED AND NOT SPRAYED WITH BORDEAUX MIXTURE 4–4–50, (VARIETIES, JOAN MARIE AND VIRGINIA), 1940

Location in summer	Average number of leafspots per plant				Mean‡
	Sprayed with bordeaux mixture before transplanting		Not sprayed with bordeaux mixture before transplanting		
	Sprayed in summer	*Not sprayed in summer*	*Sprayed in summer*	*Not sprayed in summer*	
In greenhouse.....	0	0	0	0	0
In field (old land)....	4.62	45.50	5.69	81.87	34.42
In field (new land)...	5.16	40.33	6.65	54.65	26.70
Mean*.....	3.26	28.61	4.11	45.51	
Mean†.....	15.93		24.81		

*Difference necessary for odds of 19:1 = 16.18 leafspots; for odds of 99:1 = 22.56 leafspots.
†Difference necessary for odds of 19:1 = 11.44 leafspots; for odds of 99:1 = 15.95 leafspots.
‡Difference necessary for odds of 19:1 = 14.08 leafspots; for odds of 99:1 = 19.54 leafspots.

In the 1939 experiment (table 5), applications of bordeaux mixture 4–4–50 after benching were made in conjunction with applications of D-N

dust (1) for red-spider-mite control. This combination was also used in other experiments. Early in September it appeared that the population of red spider mites in these plots was increasing and could not be checked by the dust, which was entirely effective in neighboring unsprayed plots. This effect was very noticeable several weeks later and the plants were appreciably stunted by the mites, which accounts for the highly significant reduction in flower production (table 5) on plots sprayed after benching.

If water is kept off the foliage of carnations in the greenhouse, the value of spraying with bordeaux mixture after benching is questionable. As previously pointed out, infections often appear at this time following wetting of the foliage, particularly by syringing. In preventing such infections, however, it appears more practical to recommend the adoption of measures to reduce wetting of foliage than to advise incurring the expense and inconvenience of making additional spray applications. In the control of Alternaria blight no certain advantage from spraying with bordeaux mixture after benching, either on plants sprayed or those not sprayed in the field, has yet been shown.

Timing applications in the field

The results of a factorial design experiment conducted in 1940 to determine when spraying with bordeaux mixture should be started in the field and how often applications should be made are presented in table 7. A comparison of bordeaux mixture and sulfur dust was also made in this experiment. Treatments were started: (A) May 14, (B) June 3, and (C) July 3; and applications were made (a) before rains, (b) at 10-day intervals, or (c) at 15-day intervals. All combinations of these various factors result in 18 treatments.

Approximately 7000 plants of the variety King Cardinal were used in the experiment. The 18 compound treatments were randomized in each of four beds in the field, giving four replications of each treatment. Neutral beds were planted between the experimental beds to reduce the error arising from drift of the fungicides. Treatments on the basis of rain forecasts[12] were applied at least once a week throughout the season. The plants in this experiment were transferred to the greenhouse July 20. Counts were made ten days later of the number of leafspots on 12 spaces[13] selected at random in each plot and calculations were made from these records (table 7).

The period during which carnations should be protected with fungicides in the field probably varies from one season to another. Observations have indicated, however, that conditions are often favorable for infection to occur soon after transplanting to the field. Consequently, starting applications in May as shown in table 7 may be beneficial. The differences in infection among the three dates of starting are highly significant.

The frequency with which applications of the fungicide should be made in the field will likewise probably vary with the season according to the frequency of rains and the rapidity of the plant growth. Considering practicability, a 10-day interval is probably better than a "before-rain" schedule. In regard to efficiency, applications of bordeaux mixture made at 10-day intervals gave results comparable to those obtained by making applications

[12]These forecasts were kindly furnished by the U. S. Army Meteorological Station at Mitchel Field, Garden City, New York.

[13]The spaces or hills are more uniform in size than the individual plants.

TABLE 7. A COMPARISON OF BORDEAUX MIXTURE 4–4–50 PLUS PENETROL 1–600, AND "MIKE" DUSTING SULFUR, APPLIED AT VARIOUS INTERVALS, IN THE CONTROL OF ALTERNARIA BLIGHT ON THE VARIETY KING CARDINAL, 1940

Date treatment started	Average number of leafspots per space*						
	Frequency of applications						Mean†
	Before rains	10-day intervals	15-day intervals	Before rains	10-day intervals	15-day intervals	
	Bordeaux mixture	*Bordeaux mixture*	*Bordeaux mixture*	*"Mike" dusting sulfur*	*"Mike" dusting sulfur*	*"Mike" dusting sulfur*	
May 15..	4.62	5.45	17.96	15.17	24.83	21.17	14.87
June 3...	9.92	13.83	23.75	16.12	29.50	37.54	21.78
July 3...	20.42	28.54	33.75	29.96	29.21	42.75	30.77
Mean‡	11.65	15.94	25.15	20.42	27.85	33.82	
Mean§	17.58			27.36			

*The spaces, or hills, are more uniform in size than the individual plants.
†Difference necessary for odds of 19:1 = 4.07 leafspots.
Difference necessary for odds of 99:1 = 5.56 leafspots.
‡Difference necessary for odds of 19:1 = 5.76 leafspots.
Difference necessary for odds of 99:1 = 7.87 leafspots.
§Difference necessary for odds of 19:1 = 3.32 leafspots.
Difference necessary for odds of 99:1 = 4.54 leafspots.

before rains on the basis of forecasts. In the case of sulfur dust, the difference between these two treatments is significant, with odds of 19:1, in favor of the "before-rain" schedule. Applications made at fifteen-day intervals apparently supply inadequate protection, because, with either fungicide, this treatment was inferior to the other two treatments, with odds of 99:1.

Practicability of spraying

In a discussion of the practicability of spraying for the control of foliage diseases on a high-cost crop such as carnations, one of the main considerations appears to be the convenience of making applications. The danger of spray injury resulting from applications made during the warm part of a bright summer day, and the importance of covering the foliage before rain periods often necessitate the completion of the spraying operation in a comparatively short time. One piece of equipment which has proved very convenient in this respect is a 12½-gallon, wheel-barrow type, power sprayer. The outfit, equipped with a ½-h.p. gasoline engine, supplies a pressure of from 225 to 275 pounds. The efficiency of the machine is greatly improved by attaching a two- or three-nozzle boom to the front of the sprayer.

Using the above apparatus, the total expense for a season of spraying in the field and greenhouse with bordeaux mixture 4–4–50 plus Penetrol 1–600 is estimated at about one dollar per 1000 plants. Assuming that carnations are planted at an average of 5 plants per square foot of bench, the cost of spraying is approximately 0.5 cent per square foot.

The increase in flower production from spraying with bordeaux mixture will vary with the season. The production of flowers from sprayed and unsprayed plants, in a wet season very favorable for infection, is shown in table 8. Two contiguous benches in the greenhouse were selected for this

experiment, one for each of the varieties Joan Marie and Patrician. Each bench was divided into four equal sections, giving one plot containing 282 spaces for each of the treatments listed in table 8. These plots were planted July 20–22, 1938. The plants for the "field-grown" plots were obtained from the check and some of the sprayed plots in the experiments designed for the comparison of spreaders described on pages 19–20.

TABLE 8. A COMPARISON OF FLOWER PRODUCTION FROM UNSPRAYED FIELD-GROWN PLANTS, UNSPRAYED GREENHOUSE-GROWN PLANTS, AND FIELD-GROWN PLANTS SPRAYED WITH BORDEAUX MIXTURE 4–4–50, IN A WET SEASON FAVORABLE FOR ALTERNARIA-BLIGHT INFECTION

Treatment	Production of flowers per square foot of bench, October 1, 1938 to February 24, 1939	
	Variety Joan Marie	*Variety Patrician*
1. Greenhouse-grown, unsprayed	12.89	10.02
2. Field-grown, unsprayed	4.92	4.90
3. Field-grown, sprayed after benching	5.41	4.41
4. Field-grown, sprayed in field and after benching	10.59	8.80

Eight applications of bordeaux mixture 4–4–50, to which Penetrol, linseed oil, or potassium resin soap was added as a spreader, were made from May 3 to July 19 on plots containing plants that were sprayed while in the field. Four additional applications of bordeaux mixture 4–4–50 plus Penetrol 1–800 were made in treatments 3 and 4 from July 27 to September 2. At this time very marked differences in the various treatments were apparent, in respect to amount of visible injury from Alternaria infection, and to vigor of plant growth (figure 5). The unsprayed field-grown plots and those sprayed only after benching showed marked injury from the disease. From flower-production records kept on all plots from October 1, 1938 to February 24, 1939 the average number of flowers per square foot of bench was calculated for each treatment.

It is apparent from the data in table 8 that spraying after benching alone was of no consequence in increasing flower production. On both varieties, however, field spraying practically doubled the yield in comparison with the unsprayed checks. Rough calculations from these data show that if spraying at a cost of 0.5 cent per square foot increases the yield four flowers per square foot, valued at an average price of 3 cents apiece, the net profit is $(12 - 0.5 =) 11.5$ cents per square foot of bench. In seasons less favorable for infection, field spraying may result in an increase of one flower per square foot, with odds of 19:1, as shown in table 5. Such an increase would more than pay for the cost of treatment.

SUMMARY

Alternaria blight of carnations, caused by *Alternaria Dianthi* Stev. and Hall, is considered the most serious disease of carnations on Long Island.

The suscept range of the pathogen has been extended to include *D. plumarius* Linn., *D. chinensis* var. *Heddewigii* (Linn.) Regel, and × *D. Allwoodii* Hort. Observations on, and inoculations of, various varieties of *D. caryophyllus* Linn. have shown that all are almost equally susceptible

to the disease, although under natural conditions some varieties are more consistently affected than others.

The symptoms of the disease are necrotic. The spots which develop on the leaves and sometimes on the flower calyces, in combination with cankers on the stem, finally produce a blight of the entire plant.

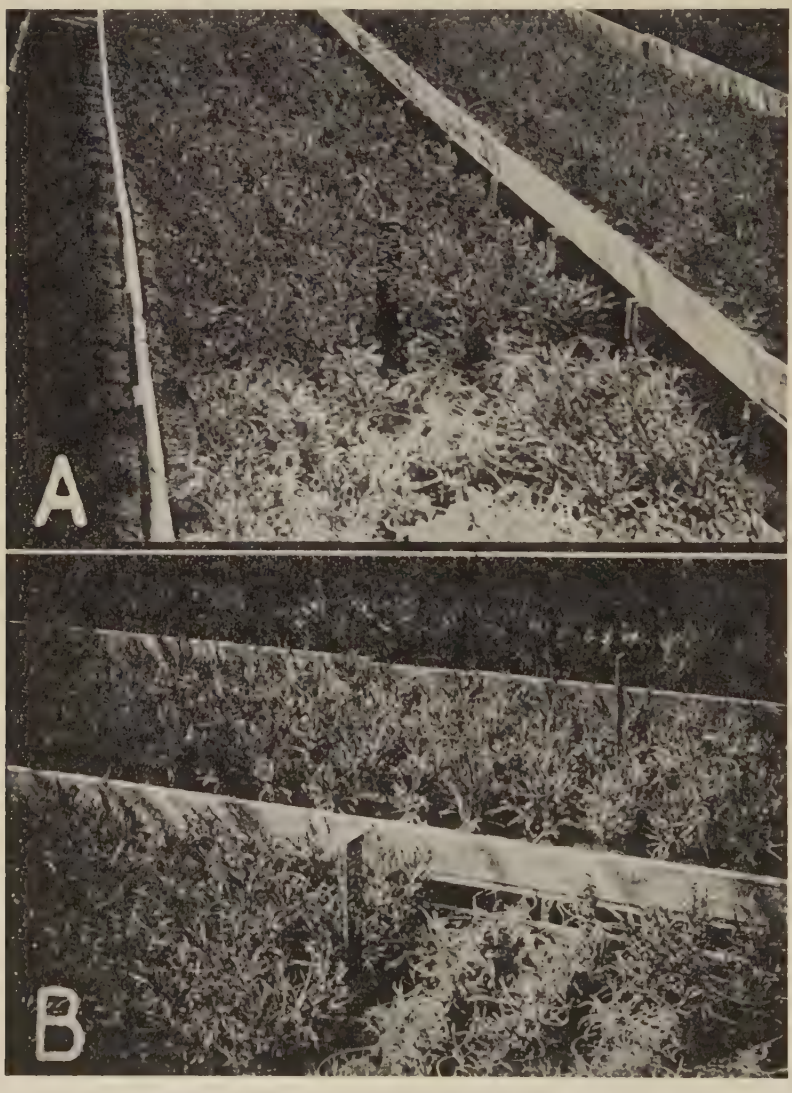


FIGURE 5. THE REDUCTION IN SEVERITY OF ALTERNARIA BLIGHT FROM SPRAYING FIELD-GROWN PLANTS OF THE VARIETY JOAN MARIE WITH BORDEAUX MIXTURE 4–4–50 IN A WET SEASON FAVORABLE FOR INFECTION

(A) Unsprayed plants in the foreground, sprayed plants in the background.
(B) A side-view of plants shown in (A).
Photograph taken September 8, 1938.

Morphological studies of the pathogen have shown a wide variation in shape, size, and septation of spores. These studies, however, do not provide sufficient evidence to warrant the creation of new species. Inoculations are described in which the pathogenicity of various isolates of *A. Dianthi* is further established.

Infested and infected cuttings represent the main source of inoculum for primary and secondary infections in the cutting bench. Similarly, the various chains of secondary lesions in the greenhouse and field are initiated by conidia developing on previous lesions. Experiments failed to demonstrate the ability of the pathogen to overwinter in the field.

Water is the most important means of disseminating the conidia. Stomata and wounds represent the infection courts for leaf infections. Stem cankers on young plants or plant parts are initiated at the nodes by the continued expansion of a leaf lesion into the stem, the coalescence of several minute stem lesions which develop on uninjured tissue, or the growth of the pathogen into wounds on the stem. Since cankers on woody stems were obtained only through wounds, it is assumed that such infections, which are frequently observed in advanced stages, occur by one of the above means before the stem becomes woody, or through growth cracks or mechanical injuries in the woody tissue.

Conidial germination occurs at temperatures covering a wide range (37° to 88° F.), but the rate is considerably reduced towards the extremes. The optimum temperature range is from 64° to 81° F., with the peak at approximately 75° F. In this optimum range, a majority of the spores germinated after eight hours. These results correlate with those from inoculation experiments in which the optimum temperature for infection was found in the neighborhood of 70° F. In a range from 60° to 80° F., it appears that, for infection to occur, moisture must be in contact with the conidia for a minimum period of eight to ten hours. Below these temperatures a longer period of wetting of the spores is necessary for infection to develop, owing to the reduced rate of spore germination. The amount of infection was shown to increase in proportion to the period of wetting of the leaf surfaces, apparently due to the proportionate increase in the number of spores which germinated.

At temperatures from approximately 67° to 81° F., the incubation period in the case of stomatal leaf infections is about 28 hours and is proportionately longer at higher or lower temperatures. Within the optimum temperature range, foliage symptoms, in connection with stem cankers, appeared 10 to 60 days after inoculation.

Plants kept in the greenhouse during the summer remain practically free of infection without the necessity of spraying, and, in a wet season favorable for infection in the field, may produce more than twice as many flowers as those grown in the field. Similarly the severity of the disease on field-grown plants is reduced by benching early.

Overhead watering in the greenhouse causes a marked spread of Alternaria blight.

Field-spraying with bordeaux mixture 4–4–50 to which is added an effective spreader such as Penetrol 1–600, or raw linseed oil 1–400, is an efficient and a practical means of appreciably reducing the severity of Alternaria blight and increasing the production of flowers. Applications should

be made either before rains or at ten-day intervals, starting soon after transplanting to the field and continuing until just prior to benching. The advantage of spraying plants with the above mixture before they are transplanted to the field has not been clearly shown. It is assumed, however, that in preventing the early infections and consequently reducing the amount of inoculum on young plants, spraying during this period will enhance subsequent control of the disease in the field. Additional applications of the fungicide after benching from the field are unnecessary if the foliage is kept dry.

REFERENCES

1. BLAUVELT, W. E., AND BICKERTON, J. K. (*Sic*). Controlling red spider on carnations. Florists exch. and hort. trade world **93**: 12. July 22, 1939.

2. CHAUDHURI, H. Annual partial wilting in *Hibiscus tiliaceus*. Indian Bot. Soc. Journ. **6**: 109–112. 1927.

3. CHRISTOFF, A. [Bulgarian title.] Some plant diseases new to Bulgaria. *Reprinted from* Renseignements agricoles, Sofia **11**[11–12]: p. 1–18. (*Abstr. in* Rev. appl. mycology **11**: 475. 1932.) 1930.

4. CLEMENTE, G. Infezioni epidemiche di un' Alternaria tipo Dianthi su semenzai di garofano. Riv. Patol. Veg., n.s., **30**: 97–115. 1940.

5. CLINTON, G. P. Carnation *Dianthus Caryophyllus*. Conn. Agr. Exp. Sta. Ann. rept. **30**: 312–313. 1907.

6. CORBETT, W. A new "wilt" disease of the carnation. Nurs. Mark. Gard. Indus. Develop. Soc. Exp. and Res. Sta. [Cheshunt, England.] Ann. rept. **13**: 42–43. 1928.

7. DELL'ANGELO, G. G. Malattie crittogamiche del garofano. Alternaria dianthi, Stev. e Hall. La costa azzurra **20**: 14–18. 1940.

8. GUBA, E. F. Leaf spot and blight of carnations. Florists exch. and hort. trade world **66**: 1503. 1927.

9. GUBA, E. F. Leaf spot and blight on carnations. Florists rev. **61**: 31. Dec. 22, 1927.

10. GUBA, E. F. Carnation blight. Mass. Agr. Exp. Sta. Bul. 247: 311. 1929.

11. GUBA, E. F. Carnation blight. Mass. Agr. Exp. Sta. Bul. 260: 343. 1930.

12. GUBA, E. F. Carnation blight. Mass. Agr. Exp. Sta. Bul. 271: 245–246. 1931.

13. GUBA, E. F. Diseases of carnations: blight and stem rot. Florists rev. **68**: 41–42. April 30, 1931.

14. GUBA, E. F. Carnation blight. Mass. Agr. Exp. Sta. Bul. 280: 205. 1932.

15. GUBA, E. F. Control of Alternaria dianthi causing a serious disease of the carnation. (Abstract.) Phytopath. **23**: 12. 1933.

16. GUBA, E. F. Some important carnation troubles and their control. American Carnation Soc. Proc. **42**: 43–71. 1933.

17. GUBA, E. F. Control for carnation diseases and insects prevalent in New England. Florists rev. **71**: 17–19. Mar. 2, 1933.

18. GUBA, E. F. Carnation blight. Mass. Agr. Exp. Sta. Bul. 315: 25. 1935.

19. GUBA, E. F. Notes on carnation blight and wilt. Florists exch. and hort. trade world **86**: 18. Mar. 17, 1936.

20. GUBA, E. F. Carnation blight, Alternaria dianthi S. & H. Mass. Agr. Exp. Sta. Bul. 339: 27–28. 1937.

21. KIRBY, R. S. Alternaria branch rot on carnation cuttings; effect of treatments. Florists exch. and hort. trade world **94**: 11. Jan. 6, 1940.

22. LYLE, E. W. The black-spot disease of roses, and its control under greenhouse conditions. Cornell. Univ. Agr. Exp. Sta. Bul. 690: 1–31. 1938.

23. MCCALLAN, S. E. A. Testing protective fungicides in the laboratory. *In* Studies on fungicides. Cornell Univ. Agr. Exp. Sta. Memoir 128: 8–24. 1930.

24. NEWTON, W., JOHNSTON, F. B., AND YARWOOD, C. Factors influencing the character of bordeaux mixture. Canadian Phytopath. Soc. Proc. (First Session): 21–26. 1930.

25. ORTON, W. A. Plant diseases in 1905. (Carnation spot, p. 611.) *In* U. S. Dept. Agr. Yearbook **1905**. 1906.

26. OVERHOLTS, L. O. Mycological notes for 1928–1929. Mycologia **22**: 232–246. 1930.

27. PASSALACQUA, T. Sopra la "Alternariosi" del garofano. Riv. Patol. Veg., n.s., **20**: 133–135. 1930.

28. STEVENS, F. L., AND HALL, J. G. Carnation alternariose. Bot. gaz. **47**: 409–413. 1909.

29. [WOODS, A. F.] Carnation pest—Alternaria. Gard. chron., 3rd. ser., **41**: 371. 1907. As quoted by the editor; source unknown.